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ORIGINAL RESEARCH

Effect of Alginate Edible Coatings Enriched with Black Cumin Extract for Improving Postharvest Quality Characteristics of Guava (*Psidium guajava* L.) Fruit

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Abstract

The influence of alginate edible coatings enriched with black cumin (BC) extract was investigated to preserve the quality of guava fruits for 16 days at 11 ± 1 °C and 85 ± 2% relative humidity. The analysis of polyphenolic compounds in BC extract confirmed the TPC (28.43 ± 1.11 mg GAE/g DM) and TFC (4.83 ± 0.17 mg QE/g DM) with strong antioxidant activity (161.69 ± 2.31 µM Trolox/g DM in DPPH and 889.19 ± 36.45 µM Fe (II)/g DM in FRAP assays). The antibacterial activity of BC extract was also proved against *Staphylococcus hominis* and *Escherichia coli* with the inhibition zone diameter. The application of alginate coatings enriched with BC extracts suppressed the respiration rate, weight loss, firmness loss, and changes in the skin color of guavas. Fruits treated with alginate coating in a combination of BC extract retarded the ripening index of guavas till the end of the storage period compared to control samples (fruits treated with distilled water). The content of vitamin C, total phenolics, and total flavonoid in fruits treated with BC extract–loaded alginate coating was significantly higher than control, alginate with $CaCl_2$, and alginate itself treatments. The antioxidant and antidiabetic activities in guava fruits coated with BC extract-based alginate coating were also comparatively higher than control and other treatments. The application of alginate coating enriched with BC extract was significantly delayed in total carotenoid formation in guavas since it delayed the ripening of fruits. Moreover, the concentrations of BC extract were worked in a dose-dependent manner in the coating systems in retarding respiration rate, weight loss, firmness loss, and ripening processes. These results proved that BC extract as a novel functional ingredient in alginate coatings was efficient in improving the quality of guava fruit and prolonging its shelf life.

Keywords Guava · Alginate coating · Extract · Total phenolics · Antioxidant activity · Quality · Storage

Introduction

Guava (Psidium guajava L.) is considered an important fruit in Bangladesh because it contains various vital micronutrients such as carotenoids, vitamin C, and polyphenols (Anjum et al., 2020). This fruit undergoes many physiological changes during and after harvest due to its climacteric nature, which accelerates metabolic processes, leading to its rapid perishability and thereby reduces storability (Arroyo et al., 2020). In addition, high temperatures accelerate the deterioration process of guava fruit after harvest. Moreover, this fruit is sensitive to chilling injury when stored at a temperature below 8 °C. The loss of quality of guava fruits is linked with prompt ripening and softening through water and firmness losses during storage. However, the quality of guava fruits can be preserved with suitable postharvest technology. Edible coating technology is a viable option due to its inexpensiveness, ease of availability, biodegradability, and effectiveness in improving the quality of different fruits and vegetables (Hassan et al., 2018; Ribeiro et al., 2021). This coating technology has been found productive in preventing the loss of weight and firmness and reducing

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the respiration rate by modifying the internal atmosphere of fruits and vegetables (Anjum et al., 2020; Reyes-Avalos et al., 2019). Various edible coatings have been formulated by incorporating natural ingredients such as lipids, proteins, and carbohydrates (Hasan et al., 2019; Hassan et al., 2018).

Alginate is a biodegradable, transparent, water-soluble, and non-toxic polysaccharide-based edible coating forming material (Tavassoli-Kafrani et al., 2016). Its fibrous chemical structure and gelling properties are suitable to fabricate excellent quality edible coatings (Zhang et al., 2018). Alginate coating has been proved to improve the quality, delay the ripening process, and extend the shelf life of fruits and vegetables such as figs (Reyes-Avalos et al., 2019), mushroom (Zhu et al., 2019), strawberry (Peretto et al., 2017), and mandarin (Chen et al., 2016). Nevertheless, its effectiveness can be enhanced by incorporating natural functional ingredients like antioxidants and antimicrobial agents (Nair et al., 2020; Ribeiro et al., 2021).

The potential functional ingredients such as antioxidants, antimicrobial, anti-browning, colorants, and nutrients enhance the performance of the basic edible coating materials during the handling, storage, distribution, and commercialization of coated products (Arroyo et al., 2020; Ribeiro et al., 2021). Recent studies have demonstrated that the application of alginate edible coating enriched with natural extracts on fruits and vegetables is gaining more acceptance over the use of chemical preservatives. For example, the alginate-based edible coating has been functionalized by carvacrol and methyl cinnamate essential oils on strawberry (Peretto et al., 2017), thyme essential oils on mushroom (Zhu et al., 2019), and pomegranate peel extract on guava (Nair et al., 2018b) and capsicum (Nair et al., 2018a) for significant improvement in their overall quality. Moreover, the gas barrier properties of edible coatings can be improved through the addition of natural plant extracts, which represent a lower O_2 and CO_2 permeability than the coating used alone (Nair et al., 2018b).

Black cumin (BC) (Nigella sativa L.) is a promising nutraceutical or medicinal food. It contains polyphenols, thymoquinone, essential fatty acids, tocopherol, antimicrobial, and cholesterol-reducing agents. Due to the presence of these active compounds, it has good antioxidant, antimicrobial, antidiabetic, and anticancer activities (Khattak et al., 2008; Soleimanifar et al., 2019; Vijayakumar et al., 2020). Recently, the use of BC has been considerably increased as a health-promoting compound in functional foods, nutraceuticals, and pharmaceutical products. For instance, BC is being used in edible vegetable oils as antioxidant (Ramadan, 2013), in cheese as antimicrobial (Mahgoub et al., 2013) and in drugs as antimicrobial and antioxidant (Vijayakumar et al., 2020). Considering these points of view, why not BC extract in alginate edible coating be used to enhance its functionality for preserving fresh fruits and vegetables? The application of alginate coating in a combination of BC extract has not been studied on guava fruits. A combination of alginate coating and BC extract may prove more effective than the application of alginate alone for extending the shelf life of guava fruits. Moreover, the information about the possible influence of this coating on respiration rate, phytochemicals such as polyphenolics and carotenoids, and bioactive properties such as antioxidant and antidiabetic activities of fruits and vegetables are very restricted.

Therefore, the present research was conducted to investigate the influence of alginate coating enriched with BC extract as a new functional ingredient on physicochemical, phytochemicals, and bioactive properties of guava fruit during storage. Different formulations of alginate coatings in a few combinations of BC extract were developed to assess the potential enhancement of postharvest quality, especially on respiration rare, polyphenolics, ascorbic acid, carotenoids content, and antioxidant and antidiabetic activities of guava fruits. This new approach increases the knowledge for the development of a more efficient edible coating for enhancing the quality of fruits with extended shelf life.

Materials and Methods

Fruit Materials

Green mature guava (Psidium guajava L.) fruits ($L^* = 55.61$, $a^* = -9.63$, $b^* = 32.33$, average values of 10 fruits) var. "Thai" were purchased from the local market in Dinajpur, Bangladesh, after 1 day of harvesting. Fruits were selected based on uniform size, shape, color, and without any defects. All fruits were washed with tap water and dried by blowing air before the application of the coatings.

Preparation of Black Cumin (BC) Extract

Black cumin (BC) (Nigella sativa L.) powder was made by grinding machine (ARTC, IC-52QC-8L80) followed by collecting, cleaning with winnowing, washing with tap and distilled water, and drying with cabinet dryer (BINDER GmbH, Germany) at temperature 55 ± 5 °C for 6–8 h to prepare BC extract. Then, the BC extract was made by the protocol of Kabir et al. (2021) by dissolving 100 g of powders in 1000 mL of 80% methanol and extracted for 1 h in a shaking water bath at 100 rpm at room temperature followed by centrifugation (General centrifuge MF, 300, HumanLab Instrument Co., Korea) at 4000 rpm for 10 min and filtration. A total volume of 150 mL of highly concentrated BC extract was obtained by evaporating methanol in a rotary evaporator (RE 100-pro, DLAB, China) at 70 °C. Finally, the extracts were ready for inclusion in edible coating materials and phenolic content and antioxidant activities analysis.

Preparation of Alginate Edible Coatings and Their Application

The alginate edible coatings enriched with BC extract were made using the procedure described by Nair et al. (2018b) with the following modification: sodium alginate (2%, w/v) were solubilized in 100 mL distilled water using a magnetic stirrer hot plate for 1 h at a controlled temperature of 70 °C until the solution becomes clear. After cooling the alginate solution at room temperature, 5% glycerol (v/v) as a plasticizer, 1% tween 20 (v/v) as surfactant, and 4% calcium chloride (v/v) as a firming agent were added in alginate solution with constant stirring for 10 min. After then, 0.5%, 1.0%, and 2.0% of concentrated BC extract were incorporated in alginate solutions and homogenized with rotor–stator homogenizer (VELP Scientifica, Italy) at 10,000 rpm for 2 min, and finally, the coating solutions were ready for application on guava fruits.

A total number of 120 guava fruits were divided into six groups and treated with the developed edible coatings. The fruits were treated/coated by dipping in distilled water (control), T1 (2% alginate + 5% glycerol + 1% tween), T2 (2% alginate + 5% glycerol + 1% tween + 4% calcium chloride), T3 (2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 0.5% BC extract), T4 (2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 1.0% BC extract), and T5 (2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 2.0% BC extract) solutions for 1 min followed by draining (Nair et al., 2018b). The treated samples were then dried by blowing air and transferred to refrigerated storage at 11 ± 1 °C and 85 ± 2% relative humidity to avoid chilling injury and water losses. Three fruits were taken from each treated group of sample for specific test and sampled at an interval of 4 days till 16 days of storage.

Antibacterial Analysis

The antibacterial activity test of BC extract–loaded alginate edible coating solutions was performed against Staphylococcus hominis (Gram-positive) and Escherichia coli (Gram-negative) bacteria by paper disc diffusion technique (Sofia et al., 2007). These bacteria were very commonly found on the surface of fruits and can cause foodborne illness (i.e., diarrhea) when eat contaminated foods. Molten sterile nutrient agar was poured into a sterile petri dish and inoculated with 0.1 mL of Staphylococcus hominis and Escherichia coli strain by spread plate technique. The sterile filter paper discs (Whatman No. 1, 5.5 mm in diameter) were dipped in different coating solutions containing 0, 0.5, 1.0, and 2% BC extract and placed on the surface of the inoculated petri dish. The petri dish was then allowed to dry in a laminar flow biological safety cabinet and incubated for 24 h at 37 °C in an inverted position. The diameter of the bacterial inhibition zones with paper discs was recorded. All the analyses were applied in triplicate.

Respiration Rate

The respiration rate of the guava fruits was determined by the glass jar technique described by García-Betanzos et al. (2017) with slight modification. Guava fruits (4 or 5 pieces of guavas) with known weight (709.3 ± 10.5 g) were placed in a 4300 mL air-tight glass jar. The probe of the multi-gas detector (CM-505, GasLab, USA) was placed inside the glass jar chamber to record the O_2 and CO_2 concentration at 25 °C at 30-min intervals until 170 h for O_2 and 7 h for CO_2. Respiration rate in terms of O_2 consumption and CO_2 production rate was calculated using the following Eqs. (1) and (2) and expressed as L kg−1 h−1:

$$RO_2 = -\left(\frac{C_{O_2}(t) - C_{O_2}(t_0)}{t - t_0}\right) \times \frac{V}{W} \quad (1)$$

$$RCO_2 = \left(\frac{C_{CO_2}(t) - C_{CO_2}(t_0)}{t - t_0}\right) \times \frac{V}{W} \quad (2)$$

where C (mL/L) is the O_2 and CO_2 concentration at time t and t_0 and t is any time other than time 0 (t_0) expressed in hours. RO_2 is the consumption rates of O_2, and RCO_2 is the production rates of CO_2, W is the product weight in kg, and V is the free volume (mL) inside the glass jar.

Measurement of Fruit Firmness, Weight loss, Ripening Index, and Surface Color

The handheld penetrometer (GY-4, Zhejiang, China) equipped with an 8-mm diameter plunger probe was used for the measurement of the firmness of guava fruit (each time, n = 3). Three readings were taken at the equatorial diameter for each guava at different locations. The test was conducted up to penetration of 10 mm into the fruit pulp, and results were expressed in kg/cm2.

The percentage of weight loss (three fruits for each treated group) in all samples was calculated using the following formula (A − B)/A ╳ 100, where A is the initial dried fruit weight after dipping treatments before storage and B is the same fruit weight after a specific storage time.

The ripening index (RI) of guava was assessed as a ratio of total soluble solids (TSS) and titratable acidity (TA). TSS of the sample was determined using a digital refractometer having the precision of ± 0.2% Brix (HI 96,800, Hanna Instruments, UK). The TA of the sample was determined by the AOAC titrimetric method (AOAC, 1996).

The colorimeter (BCM-200, Biobase, China) was used to measure the color parameters such as L*(lightness), a*(greenness), and b*(yellowness) values of the surface of

guava fruits. The samples were read using specular reflectance induced with D65 illuminant and 8° observer angle. The measurements were taken in the three locations of each guava surface at 0, 4, 8, 12, and 16 days of storage.

Vitamin C and Total Carotenoid Content

Vitamin C content was determined by the titration method (AOAC, 1990). In brief, 4 g of fruit pulp was mashed by mortar and pestle and mixed with 10 mL of 20% metaphosphoric acid solution and filtered through Whatman No. 1 filter paper. After that, we transferred 1 mL of filtrate in a small beaker and mixed it with 10 mL of distilled water. Then, 2 mL of this solution was transferred into another beaker, shaken, and titrated against 2,6-dichlorophenolindophenol solution until the pink color appeared. Vitamin C content was calculated according to Eq. (3) as follows:

$$Vitamin\ C(\frac{\text{mg}}{\text{g}}) = \frac{\text{Dyefactor}\left(\frac{mg}{mL}\right) \times \text{Titre value (mL)} \times \text{Volume made up (mL)}}{\text{Aliquottaken (mL)} \times \text{sample weight (g)}} \quad (3)$$

The total carotenoid content was quantified according to the method of Anjum et al. (2020). Briefly, 5 g of fruit pulps was mashed by mortar and pestle and mixed with 50 mL of n-hexane–acetone-ethanol in a 50:25:25 (v/v) ratio in a conical flask. Then, the extraction of carotenoids was performed in a shaking water bath at 100 rpm for 10 min at room temperature. Afterward, the sample was centrifuged at 6500 rpm for 5 min at 4 °C and collected the supernatants and made up the volume 50 mL with the extraction solvent. The absorbance was recorded at 450 nm, and the results were expressed as μM β-carotene equivalent per g fresh fruits using (0, 10, 20, 30, 50, 100, 200, 300 μM) β-carotene as standard.

Preparation of Guava Fruit Extract

Guava fruit extracts were prepared at a regular interval of 4 days during storage by weighing 5 g of fresh guava fruits, mashed, and mixed with 50 mL of 80% methanol and extracted by applying the same procedure as BC extract preparation. The obtained extracts were analyzed for the total phenolic and flavonoid content, antioxidant, and antidiabetic activities.

Total Phenolic Content (TPC) and Total Flavonoid Content (TFC)

The TPC and TFC of guava fruit were assessed by Folin–Ciocalteu assay and the $AlCl_3$ (aluminum chloride) colorimetric assay with the protocol of Singleton and Rossi (1965) and Islam et al. (2021) with some modification, respectively. The results of TPC and TFC were expressed as mg gallic acid equivalent per g of fresh weight (mg GAE/g fresh weight (FW)) and mg of quercetin equivalent per g of fresh weight (mg QE/g FW), respectively.

Antioxidant Activities

DPPH·-scavenging ability and ferric-reducing antioxidant power (FRAP) assays were performed to evaluate the antioxidant activities of the guava extracts. The DPPH· scavenging ability assay was performed using the protocol of Brand-Williams et al. (1995) with some modifications. The reduction of DPPH· was measured by a UV–VIS spectrophotometer by recording the absorbance at 515 nm of the mixture of 50 μL extracts and 1.950 mL of 0.13 mM DPPH· solution immediately after 30 min of incubation at room temperature. All the tests were performed in triplicate. The results were expressed as μM Trolox equivalents/g dry matter (DM) or g fresh weight (FW), respectively, using Trolox as standard.

Ferric-reducing antioxidant power (FRAP) assay was carried out following the procedure of Nair et al., (2018a, b) with slight modification. In detail, the FRAP reagent was prepared by using acetate buffer (pH 3.6), 20 mM iron(III) chloride solution, and 10 mM TPTZ (2,4,6-Tris(2-pyridyl)-s-triazine) solution in 40 mM HCl in 10:1:1 (v/v) ratio, respectively. The FRAP reagent was prepared daily and was warmed to 37 °C in a water bath before use. The extracts of 25 μL were added to 1.975 mL of the FRAP reagent, and the absorbance of the reaction mixture was recorded at 593 nm after 4 min of incubation. The results were expressed as μM Fe(II) equivalents/g dry matter (DM) or g fresh weight (FW), respectively, using iron(II) sulfate solution (100–2000 μM) as standard.

α-Glucosidase Inhibitory Activity

To investigate the antidiabetic activity of guava fruits, the α-glucosidase inhibition activity of the guava extracts was performed by recording the absorbance at 405 nm by UV–VIS spectrophotometer according to Islam et al. (2021). The inhibition percentage was calculated according to Eq. (4):

$$\text{Inhibition percentage}\ (\%) = \frac{(A_c - (A_s - A_b))}{A_c} \times 100 \quad (4)$$

where A_c is the absorbance of the control (without sample), A_s is the absorbance of the sample, and A_b is the absorbance of the sample blank (without p-Nitrophenyl-α-D-glucopyranoside solution).

Statistical Analysis

The experiment design was completely randomized in a 6×5 factorial scheme. Sources of variation were coating treatments and storage time. The data were statistically analyzed for significance (at $p < 0.05$) by a two-way analysis of variance (ANOVA) using SPSS software (version 22, USA). The means were compared by Duncan's multiple comparison tests. The values were presented as mean values ± standard deviation.

Results and Discussion

Antioxidant and Antibacterial Activity of Black Cumin Extract

The antioxidant capacity of BC extract was evaluated in terms of TPC, TFC, DPPH·-scavenging ability, and FRAP, and shown in Table 1. The values of TPC and TFC were higher than Khattak et al. (2008) and Hameed et al. (2019) who reported 4.1 mg GAE/g DM, 292.5 ± 9.1 mg GAE/100 g DM, and 188.8 ± 5.7 mg QE/100 g DM, respectively. The higher amount of TPC and TFC could be due to the concentrated form of BC extract in this study as it was concentrated from 1000 to 150 mL. Moreover, the influence of the variety, growing conditions, harvesting time, pretreatment, and methods of determination might be affected in TPC and TFC of BC extract (Islam et al., 2021). As expected, the high contents of TPC and TFC in BC extract were likely responsible for high antioxidant activity measured by DPPH· and FRAP assays: DPPH· represents 161.69 ± 2.31 μM Trolox equivalents/g DM, and FRAP represents 889.19 ± 36.45 μM Fe (II) equivalents/g DM. Khattak et al. (2008) noticed 79.4% to 92.0% DPPH· scavenging activity, and Hameed et al. (2019) found 52.8 μg/mL IC50 values in DPPH·-scavenging assay and 5.53 mg Trolox equivalent/g sample in FRAP assay in BC extract which might be consistent with this study. Nevertheless, the above-mentioned results showed great capability toward the use of BC extract as natural antioxidant ingredients in edible coating systems.

The results of the antibacterial activity test of BC extract–loaded alginate coating solutions against Staphylococcus hominis (Gram-positive) and Escherichia coli (Gram-negative) bacteria were shown in Table 1 and Fig. 1. Expectedly, the BC extract incorporated alginate coating showed antibacterial activity, but the control (without BC extract) did not show any antibacterial activity. The higher the concentration of BC extract, the higher diameter of the inhibition zones (mean higher antibacterial activity) against both types of bacteria. In the case of 2.0% BC extract, it markedly increased the inhibitory effect of the alginate coating on both Staphylococcus hominis (10.01 ± 0.10 mm inhibition zone) and Escherichia coli (8.85 ± 0.13 mm inhibition zones) bacteria. The BC extract-enriched coatings showed stronger antibacterial activity against Gram-positive bacteria than Gram-negative bacteria. The bacterial inhibition zone depends on the type of bacteria, cell wall structure, cell thickness, and additional antibacterial substances (Roy & Rhim, 2020). The cell wall of Gram-negative bacteria is more complex due to the presence of an outer membrane composed mainly of lipopolysaccharide, and the thin peptidoglycan layer acts as a barrier and reduced bioactive compounds into the cell (Noori et al., 2018). Moreover, different kinds of polyphenol exert different effects on bacterial, and the combination of different polyphenols is much more active than any polyphenol alone (Luo et al., 2019). Luo et al. (2019) and Wu et al. (2019) reported that the addition of guava leaf extract and tea polyphenols, respectively, significantly promoted the antimicrobial activity of

Table 1 Antioxidant and antibacterial activities of BC extract

Antioxidant activity		Antibacterial activity		
		Diameter of inhibition zone (mm)		
			S. hominis	*E. coli*
TPC (mg GAE/g DM)	28.43 ± 1.11	Control	———	———
TFC (mg QE/g DM)	4.83 ± 0.17	T_3	8.89 ± 0.29	8.09 ± 0.48
DPPH· (μM Trolox/g DM)	161.69 ± 2.31	T_4	9.24 ± 0.53	8.45 ± 0.08
FRAP (μM Fe (II)/g DM)	889.19 ± 36.45	T_5	10.01 ± 0.10	8.85 ± 0.13

Results are the mean ± standard deviation of at least three determinations ($n = 3$)

T3 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 0.5% BC extract

T4 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 1.0% BC extract

T5 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 2.0% BC extract

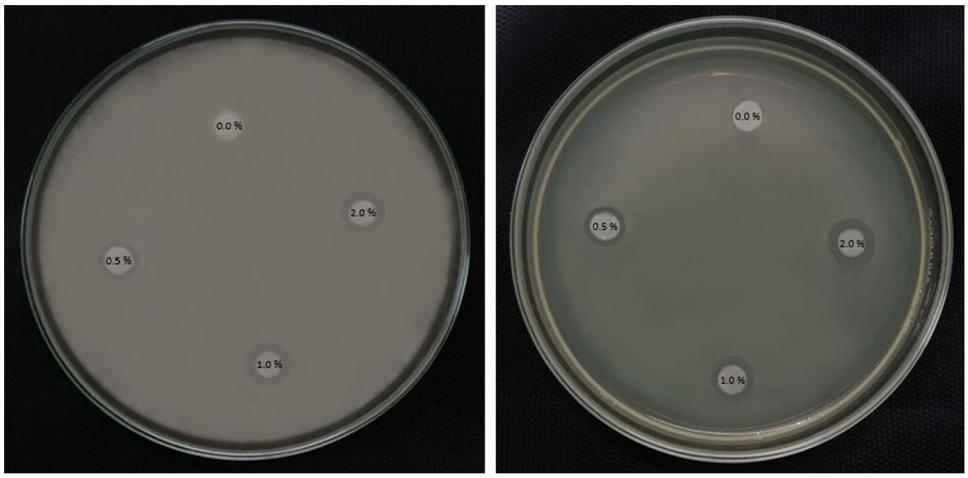


Fig. 1 Disc diffusion test of 0, 0.5, 1, and 2% BC extract–loaded alginate coatings for *Staphylococcus hominis* and *Escherichia coli*

the composite coatings/film compared with the control; the similar results were obtained in this study.

Respiration Rate

The change in the respiration rate of guava fruits subjected to various treatments was shown in Fig. 2. As the initial concentration of O_2 and CO_2 in all glass jars was approximately the same, the initial value of respiration rate for all treatments was similar. The O_2 consumption rate was rapid up to 15 h and then progresses with a slight increase. Not surprisingly, the fruits coated with BC extract–loaded alginate coatings showed a significantly ($p < 0.05$) low consumption rate of O_2 than the control. The higher the concentration of BC extract in the coating system, the lower the O_2 consumption rate of the coated fruits. A similar trend was also observed in the CO_2 production rate (inset of Fig. 2) of coated and uncoated guava fruits. As the instrument has a limit to detect CO_2 concentration, we had measured CO_2 production rate until the time to reach its maximum detection level. The rate of CO_2 production in the uncoated control sample was fast and reached its maximum level of detection within 30 min. In the case of coated samples, the CO_2 production rate was delayed significantly and reached its maximum level of detection after 6.5 h. Overall, the study was able to show that the alginate coatings enriched with BC extract were able to reduce the respiration rate of coated fruits by delaying O_2 consumption and CO_2 production rate. The reduction of respiration rates of guava fruits due to the application of BC extract–loaded alginate edible coating was agreed with the findings of Gardesh et al. (2016), Hasan and Nicolai (2014), and García-Betanzos et al. (2017) on apple, pear, and guava fruits, respectively. The antimicrobial and lipophilic properties of BC extract might be enhanced the barrier properties of the coatings (Fig. 1), thus restricting the gas diffusion on reducing the respiration rate (Nair et al., 2018a, b). Consequently, this coating was effective to modify the internal atmosphere of guava fruits by inhibiting the consumption of O_2 and the production of CO_2 to a significant level which could improve the quality of fruits.

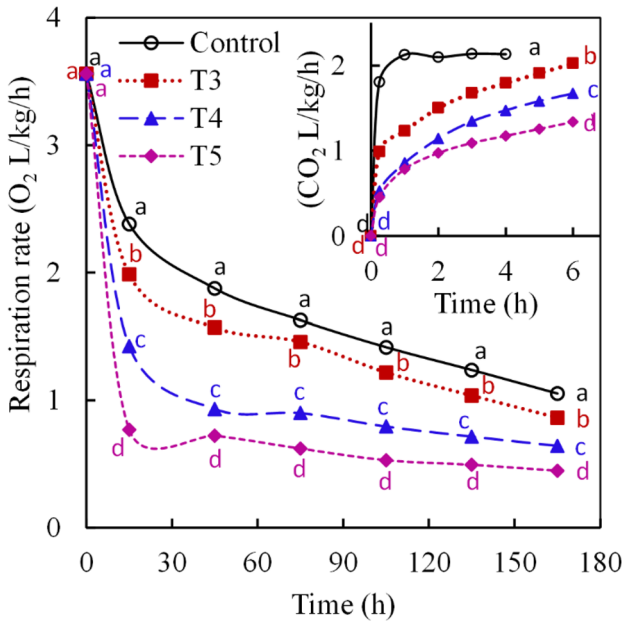


Fig. 2 Respiration rate of guava fruit at 25 ± 2 °C. Note: T3 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 0.5% BC extract, T4 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 1.0% BC extract, and T5 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 2.0% BC extract; and different letters (a, b, c, and d) indicate significant differences at $p < 0.05$

Firmness

The changes in fruit firmness among control and treated samples were observed during 16 days of storage at

11 ± 1 °C and shown in Fig. 3A. Initially, the firmness value was similar with slight variation for both control and treated samples. As the day of storage progresses, all samples began to show a gradual loss of firmness, but the treated samples exhibited significantly ($p < 0.05$) higher firmness in comparison to the control sample at 8, 12, and 16 days of storage. The treatments T1, T2, T3, T4, and T5 were more effective in maintaining the highest level of fruit firmness. Regarding BC extract, the coating of 2.0% extract was more efficient in preventing loss of fruit firmness during storage.

Guava fruits are usually subjected to loss of firmness during ripening which subsequently leads to their short postharvest life and decreases quality (Hong et al., 2012). The loss of firmness in fruits could be due to changes in the composition of the cell wall especially pectin materials that are responsible for cell wall integrity (Mannozzi et al., 2018). As fruits ripen, the major enzymes such as polygalacturonase, pectin methylesterase, and pectate lyase degrade the cell wall, thus resulting in depolymerization and solubilization of pectin polysaccharides (Jain et al., 2001). Several studies reported that the application of alginate coating and its enrichment with essential oils and antioxidant was more effective in reducing the activities of polyphenol oxidase, peroxidase, and cellulase on jamun fruit (Baraiya et al., 2015) and mushroom (Zhu et al., 2019) and the activities of polygalacturonase and pectin methylesterase on carambola fruits (Gol et al., 2015). In this study, the higher retention of firmness of guava fruits coated with BC extract-enriched alginate coating could be due to the lower activity of enzymes within the cell wall which resulted in a slower rate of degradation. Moreover, adding BC extract to the alginate polymeric matrix can increase the hydrophobic nature of the coating, thereby reducing the water vapor permeability of the coatings (Luo et al., 2019). Furthermore, the maintenance of firmness in guava fruits treated with BC extract-enriched alginate coatings could be due to their antimicrobial activity and covering of cuticle and lenticels, thereby reducing infection, respiration, and other ripening processes during storage (Arroyo et al., 2020; Luo et al., 2019). Similar results also noticed when alginate coating enriched with pomegranate peel extract on guava (Nair et al., 2018b),

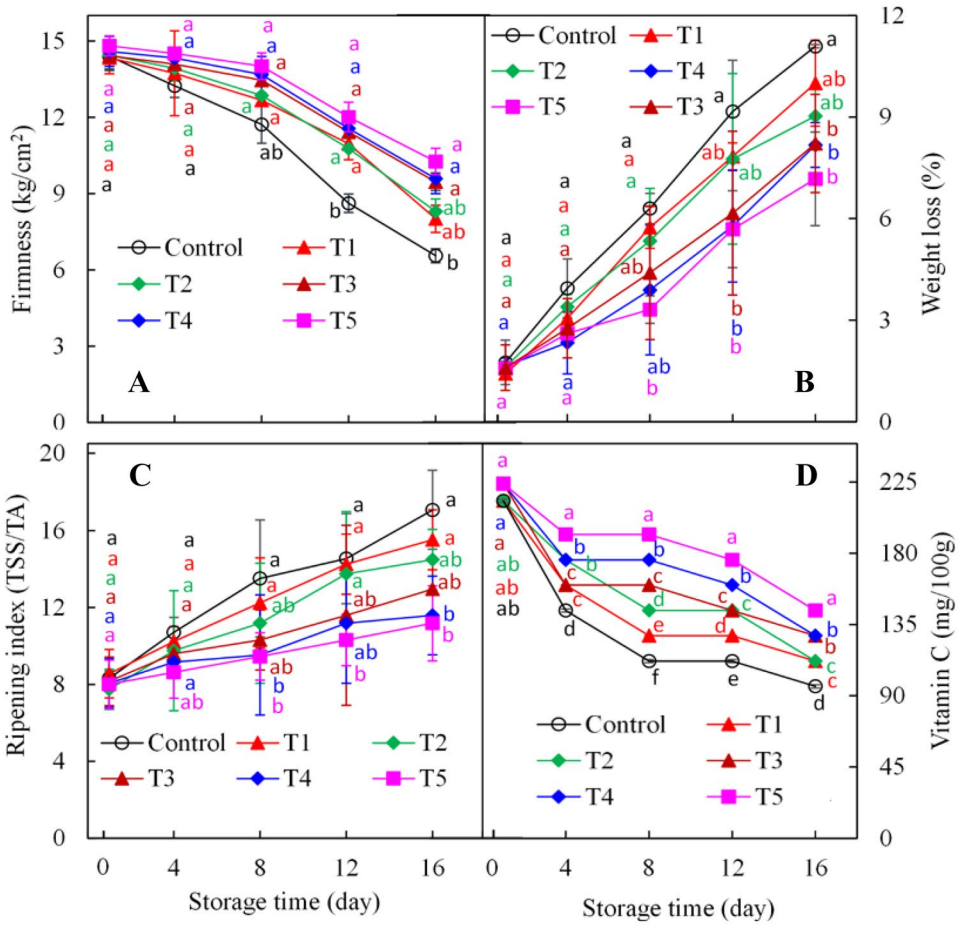


Fig. 3 Effect of alginate coating enriched with BC extract on the firmness (**A**), weight loss (**B**), ripening index (**C**), and vitamin C content (**D**) of guava fruits stored at 11 ± 1 °C and 85 ± 2% RH for 16 days. Note: T1 = 2% alginate + 5% glycerol + 1% tween, T2 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride, T3 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 0.5% BC extract, T4 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 1.0% BC extract, and T5 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 2.0% BC extract; and different letters (a, b, c, d, e, and f) indicate significant differences at $p < 0.05$

Ficus hirta fruit extract on mandarin (Chen et al., 2016), and essential oil on strawberry (Guerreiro et al., 2015).

Weight Loss

The percentage weight loss of uncoated control and coated samples during 16 days of storage period at 11 °C were reported in Fig. 3B. Fruit weight loss increased in all the treatments assessed during storage. However, there was an added benefit to control and alginate coating of weight loss by increasing the concentration of BC extract from 0.5 to 2.0%. For instance, the weight loss of guava fruits was significantly ($p < 0.05$) reduced in 2.0% BC extract–loaded alginate coating (T5) followed by 1.0 (T4) and 0.5% (T3) and then control and alginate coating (T2 &T1) at 8, 12, and 16 days of storage. At the end of storage, 2.0% BC extract–loaded alginate coating had a beneficial effect on reducing the weight loss of guava fruits by 35%.

The loss of weight in fresh fruits is mainly due to the loss of water caused by metabolic activities such as respiration and transpiration (Rehman et al., 2020). Alginate coating forms a thick semipermeable layer to the skin of the fruit surface which acts as a protective barrier against gases such as O_2, CO_2, and water vapor of the internal atmosphere around the fruits, thus resulting in low respiration and transpiration rates through the fruit surfaces (Luo et al., 2019). Moreover, Emamifar and Bavaisi (2020) noticed that alginate coatings enriched with nano-ZnO were created tortuous pathway which limited the water vapor, O_2, and CO_2 exchange between inside and outside of the coated fruits and resulted in reducing fruit surface evaporation and respiration. The inclusion of BC extract to alginate edible coating might be functionally similar to adding nano-ZnO that modify alginate polymer matrix and improve the functions of the coatings. These modifications of alginate coating enriched with BC extract were effective in conferring a physical barrier to water loss; therefore, a decrease in weight loss in the coated fruits was noticed during storage. The results of this study were parallel with the results of pomegranate peel extract (Nair et al., 2018b), and ZnO nanoparticles (Arroyo et al., 2020) loaded alginate coating on guava fruits. Apart from guava fruit, alginate coatings enriched with essential oil, capsaicin, and nano-ZnO particles were effective to reduce the water vapor permeability which restricted the moisture loss in fresh-cut apples (Zhang et al., 2018) and strawberries (Emamifar & Bavaisi, 2020), respectively.

Ripening Index (RI)

A continuous increase in RI (TSS/TA ratio) in all the treatments tested during storage (Fig. 3C). However, alginate coatings with BC extract considerably ($p < 0.05$) prevented the increase in RI of guava fruits at 8, 12, and 16 days of storage in comparison with control, alginate itself (T1), and alginate with $CaCl_2$ (T2). Among the concentration of BC extract, 2.0% (T5) showed the highest restriction followed by 1.0% (T4) and 0.5% (T3). This means these coatings have a positive effect to retard the ripening of guava fruits in comparison with control and other coatings. Similar results were also found in Spondias tuberosa fruit coated with pomegranate seed oil enriched edible coating (de Medeiros Teodosio et al., 2021); blueberries coated with chitosan-based coating enriched with procyanidin by-products (Mannozzi et al., 2018).

As the water content was decreased, and the polysaccharides and organic acids were converted to sugar, the TSS content tends to show an increase during the storage of guava fruits (Etemadipoor et al., 2020). However, the content of TA usually tends to decline over storage as the organic acids burnt out during metabolic processes (Gol et al., 2015). In this study, the values of TSS were almost stable with a slight increase ($p > 0.05$) during storage. A decreasing trend of the TSS value in coated fruits was observed with the increasing concentration of BC extract in the alginate coatings. On the other hand, the TA values were significantly ($p < 0.05$) decreased during storage, but BC extract–loaded alginate coatings were prevented the loss of TA values. The retention of TSS and TA values might be the slower respiration rate and weaker metabolic activity, thus resulting in a delay ripening process. Nair et al. (2018b) also confirm that chitosan and alginate-based coating enriched with pomegranate peel extract was effective in preventing the loss of TSS and TA values of coated guava during storage.

Vitamin C Content

As depicted in Fig. 3D, the vitamin C content of the guava fruits was found to be decreased with the extension of the storage period regardless of the treatments, being lower in the coated fruits. The loss of vitamin C in the fruits coated with 0.5% (T3), 1.0% (T4), and 2.0% (T5) BC extract–loaded alginate coatings was significantly ($p < 0.05$) lower compared to alginate itself (T1), alginate with $CaCl_2$ (T2), and control during the entire storage period. The vitamin C content in fruits and vegetables declines due to advanced fruit maturity, senescence, and oxidative breakdown (Anjum et al., 2020). However, the main cause of vitamin C degradation in fruits and vegetables might be oxidation (Lee & Kader, 2000), which depends upon the availability of O_2 during storage. The application of edible coatings on fruits and vegetables acts as a protective layer to limit O_2 uptake/permeability, thereby leading to inhibit vitamin C degradation (Ali et al., 2021). Perhaps, alginate coatings enriched with BC extract reduced the diffusion of O_2 which inhibited the oxidation-based deteriorative reactions in guava fruits in this study. It suggested that the atmosphere created (Fig. 2)

by alginate coating enriched with BC extract was effective in preserving vitamin C content in guava fruits. The higher levels of vitamin C content in guava fruits coated with BC extract-enriched alginate coatings could also be due to higher phenolic compounds in BC extract which could improve the antioxidant activity of coatings (Etemadipoor et al., 2019). Moreover, these findings were in accordance with those reported for guava (Nair et al., 2018b) and mandarin (Chen et al., 2016) fruits coated with alginate coatings enriched with pomegranate peel extract and Ficus hirta fruit extract, respectively.

Surface Color

The color of fruit peel is an important parameter for consumers, which indicates the quality of fruit in terms of maturity and harvest time. Accordingly, the changes in peel color parameters such as L*, a*, and b* values of uncoated control and coated guava fruits during storage at 11 °C were measured and shown in Table 2. The values of the L* and b* parameters of fruits were non-significantly ($p > 0.05$) varied in all the treatments during storage; however, the a* value of the 2.0% BC extract-coated fruits was varied significantly ($p < 0.05$) on the 12th and 16th day compared to control. The changes of fruit peel color were revealed by a decrease in L* value, which is indicated in the reduction of lightness during storage. The most lightness was obtained in fruits treated with 2.0, 1.0, and 0.5% BC extract-enriched alginate coating. The a* value index was increased during storage which tends to become less green and turning to red. The lowest a* value was recorded in guava treated with 2.0% BC extract coating followed by 1.0 and 0.5% BC extract-enriched alginate coating. Increasing the b* value during storage of guava fruits indicates the skin color becomes more yellow. The lowest value of this index was noticed in fruits treated with 2.0, 1.0, and 0.5% BC extract-enriched alginate coating, respectively, and the highest value was in the control sample. During the ripening of guava fruits, the skin color of this fruit changes from green (mature) to yellow (ripe). In this study, we observed less light ($\Delta L < 0$), less green ($\Delta a > 0$), and more yellow ($\Delta b < 0$) color in guava fruits due to the degradation of chlorophyll pigments and

Table 2 Changes in the *L*, *a*, and *b* values in surface color of uncoated and coated guava fruits during storage at 11 ± 1 °C and 85 ± 2% relative humidity

Color parameter	Treatment	Time (days)				
		0	4	8	12	16
L value*	Control	55.63 ± 1.02^{a}	54.92 ± 1.05^{ab}	53.14 ± 0.07^{b}	52.95 ± 0.82^{bc}	52.73 ± 0.68^{bc}
	T1	55.64 ± 1.72^{a}	54.42 ± 0.48^{ab}	54.63 ± 0.53^{ab}	54.25 ± 0.37^{ab}	53.10 ± 0.42^{b}
	T2	55.87 ± 1.06^{a}	54.62 ± 0.11^{ab}	54.64 ± 0.95^{ab}	54.18 ± 0.29^{ab}	53.12 ± 0.62^{b}
	T3	55.69 ± 1.70^{a}	54.88 ± 1.05^{ab}	54.71 ± 0.35^{ab}	54.51 ± 0.67^{ab}	53.18 ± 0.60^{b}
	T4	55.65 ± 0.84^{a}	55.14 ± 0.45^{a}	54.82 ± 0.52^{ab}	54.55 ± 0.18^{ab}	53.47 ± 0.15^{b}
	T5	55.88 ± 0.62^{a}	55.35 ± 0.71^{a}	55.14 ± 0.46^{a}	55.09 ± 0.87^{a}	54.55 ± 0.09^{a}
a value*	Control	-9.76 ± 0.40^{a}	-8.29 ± 0.14^{b}	-7.37 ± 0.22^{c}	-6.83 ± 0.18^{b}	-6.27 ± 0.37^{c}
	T1	-9.75 ± 0.11^{a}	-8.44 ± 0.12^{b}	-8.34 ± 0.12^{ab}	-7.08 ± 0.27^{b}	-6.83 ± 0.34^{bc}
	T2	-9.75 ± 0.37^{a}	-8.46 ± 0.12^{b}	-8.49 ± 0.27^{ab}	-7.15 ± 0.73^{b}	-6.82 ± 0.48^{bc}
	T3	-10.02 ± 0.19^{a}	-8.63 ± 0.25^{ab}	-8.60 ± 0.17^{ab}	-8.51 ± 0.33^{ab}	-7.46 ± 0.30^{b}
	T4	-10.03 ± 0.26^{a}	-9.60 ± 0.20^{a}	-9.03 ± 0.39^{a}	-8.72 ± 0.11^{ab}	-8.05 ± 0.46^{ab}
	T5	-10.05 ± 0.29^{a}	-9.71 ± 0.47^{a}	-9.47 ± 0.13^{a}	-9.33 ± 0.82^{a}	-9.17 ± 0.30^{a}
b value*	Control	32.33 ± 0.69^{a}	32.23 ± 1.37^{a}	32.66 ± 0.63^{a}	32.94 ± 1.73^{a}	33.98 ± 0.78^{a}
	T1	32.15 ± 0.13^{a}	32.21 ± 2.43^{a}	32.81 ± 0.25^{a}	32.77 ± 0.24^{a}	32.96 ± 0.43^{ab}
	T2	32.34 ± 1.30^{a}	31.59 ± 1.20^{a}	32.71 ± 0.14^{a}	32.79 ± 0.47^{a}	33.76 ± 0.34^{a}
	T3	32.35 ± 0.84^{a}	30.84 ± 1.57^{b}	31.66 ± 1.19^{ab}	32.28 ± 1.47^{ab}	32.28 ± 0.54^{ab}
	T4	32.03 ± 0.55^{a}	30.75 ± 0.33^{b}	32.21 ± 1.02^{ab}	32.33 ± 0.13^{ab}	33.22 ± 0.82^{ab}
	T5	31.07 ± 0.72^{a}	30.90 ± 1.12^{b}	31.94 ± 0.91^{ab}	32.07 ± 0.44^{ab}	32.18 ± 0.43^{ab}

Results are the mean ± standard deviation of at least three determinations ($n = 3$). Within a column, different letters (a, b, c) denote significant differences ($p < 0.05$) between the control and treated guava fruits

T1 = 2% alginate + 5% glycerol + 1% tween

T2 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride

T3 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 0.5% BC extract

T4 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 1.0% BC extract

T5 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 2.0% BC extract

formation of carotenoids (Palou et al., 1999). However, coated guava fruits showed lower changes and higher retention of peel color, which indicates the reduction in ripening processes during storage. Figure 4 represented the overall visual appearance of coated and uncoated fruits during each assessment day. In line with the results of this study, the use of chitosan and alginate coating enriched with pomegranate peel extract showed a positive effect on the color retention in guava (Nair et al., 2018b). Also, the application of gum arabic in the combination with cinnamon essential oils preserved the color of guava fruits at 10 °C (Etemadipoor et al., 2019). Moreover, Arroyo et al. (2020) reported that a modified atmosphere is created between the surface of the fruit and the applied coating prolongs the degradation of pigments by the absence of O_2 and therefore slows down the development of undesirable colors.

Total Carotenoid Content

The total carotenoid in guava fruits was found to be significantly ($p < 0.05$) influenced by the treatments and storage time (Fig. 5A). The carotenoid content was increased rapidly ($p < 0.05$) in control followed by alginate itself (T1), alginate with $CaCl_2$ (T2), and alginate with BC extract treatments (T3, T4, and T5) over storage time. This indicates that the control sample turns to more red color ($\Delta a > 0$) during storage, resulting in more carotenoid. As expected, the application of coating delays the ripening process, resulting in delay in carotenoid formation. Moreover, the carotenoid content was dose-dependent for BC extract-coated samples; the higher the extract percentage, the lower the total carotenoid content. Carotenoid content generally increases during the ripening process and changes the color of fruits

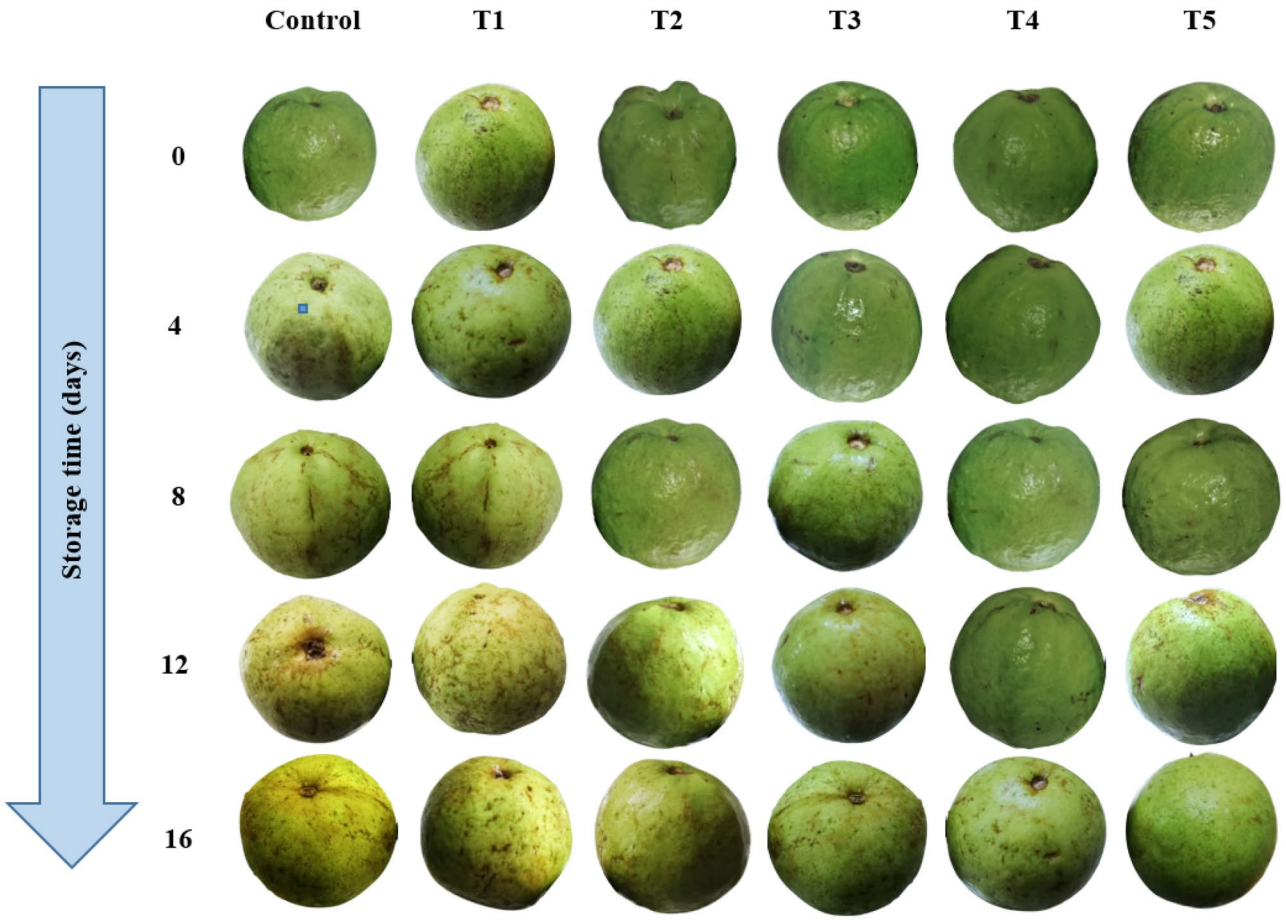


Fig. 4 The visual appearance of guava fruits after coating treatments during storage at 11 ± 1 °C and 85 ± 2% RH. Note: T1 = 2% alginate + 5% glycerol + 1% tween, T2 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride, T3 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 0.5% BC extract, T4 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 1.0% BC extract, and T5 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 2.0% BC extract

(Saleem et al., 2020). Daisy et al. (2020) reported that the total carotenoid content might be correlated with the change in fruit color. So, it is important to maintain the carotenoid content in guavas, as these molecules have bioactive properties to deliver a defense to counter many degenerative processes (Rehman et al., 2020). Although higher retention of carotenoids is considered beneficial, any treatment that can retain higher carotenoids is suitable. However, alginate coating enriched with BC extract was effective in delaying the increase in carotenoid content, possibly by interrupting the ripening-related metabolic function. Similar results were also observed by Etemadipoor et al. (2020) who reported lower carotenoid content in gum arabic coating enriched with essential oil fruits treated guava than control fruits.

Total Phenolic Content (TPC)

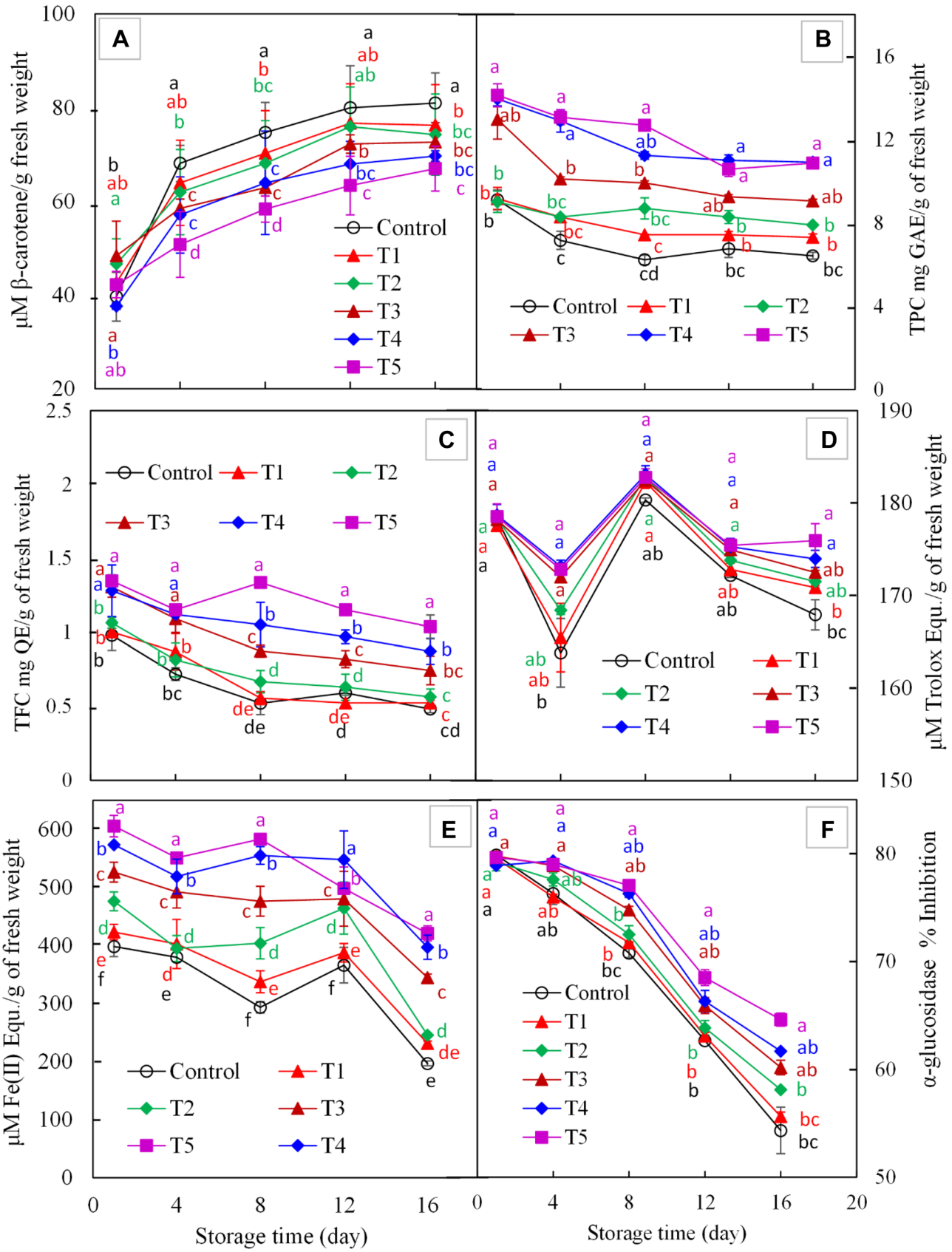
The changes in the TPC in treated and control fruits during storage were shown in Fig. 5B. On the initial day of storage, a difference in TPC was observed in the fruits coated with BC extract-enriched alginate coatings compared to control and fruits coated with alginate and alginate with $CaCl_2$. This difference might be due to the incorporation of BC extract in the coating systems which was a rich source of phenolic content. However, the influence of treatments and storage time on TPC in guava fruits was significant ($p < 0.05$). The TPC was high ($p < 0.05$) in 2.0% (T5) and 1.0% (T4) treated guava fruits followed by 0.5% (T3) BC extract-enriched alginate, alginate with $CaCl_2$ (T2), alginate itself (T1), and control samples during the whole period of storage. Moreover, a slight increased and decreased trend was observed among the treatments on TPC in fruits. Anjum et al. (2020) reported that the concentration of phenolic compounds generally increases with ripening and then subsequently reduces due to oxidation reactions and senescence. However, the phenolic content greatly decreases due to oxidation (Ali et al., 2021). Khaliq et al. (2019) reported that the application of the edible coating on fruits could slow down the ripening process and contribute to higher retention of phenolic compounds. In this work, alginate coating application in combination with BC extract possibly reduced the oxidation and effectively preserved higher phenolic content in guava fruits during storage. Our present results were in line with the work of Khaliq et al. (2019) and (Yang et al., 2019) as in their findings total phenolics were also found to be higher in response to the application of aloe vera gel and gum arabic coatings enriched with plant extract on sapodilla fruit and blueberry fruit, respectively.

Total Flavonoid Content (TFC)

As shown in Fig. 5C, the TFC in coated guava fruits on the initial day was higher like TPC. The influence of treatments and storage time on TFC in guava fruits was also significant ($p < 0.05$). The TFC in guava fruits was decreased as the storage period progressed irrespective of treatments. However, the reduction of TFC in all treated fruits was comparatively slow than control. During the entire storage period, the maximum retention of TFC was found in guava fruits treated with BC extract-enriched alginate coatings. The retention of TFC was observed in a dose-dependent manner with respect to BC extracts. The depletion of the TFC in fruits might be attributed to its conversion to secondary phenolic compounds during the ripening process or due to the high metabolic activity of the enzymes (Howard et al., 2003). The application of edible coating limits the flow of oxygen moving in and out of the fruit which lowers the activity of phenol-degrading enzymes, resulting in restricted changes in flavonoid content (Etemadipoor et al., 2020). Earlier studies demonstrated that the losses of TFC have been restricted as the effect of coating in various fruits such as litchi coated by chitosan coating (Zhang & Quantick, 1997); guava coated by alginate coating in combination with pomegranate peel extract (Nair et al., 2018b); and gum arabic coating in combination with essential oils (Etemadipoor et al., 2020). These studies agreed with the findings of this work since BC extract-coated fruits had higher retention of TFC than other samples at the end of the storage period.

Antioxidant Activity

Figure 5D, E showed the antioxidant activity of guava fruits treated with BC extract-enriched alginate coatings during storage. The changes in the antioxidant activity were approximate like the trend observed in the TPC and TFC. The highest antioxidant activity was recorded in alginate with 2.0% (T5) BC extract-coated fruits both in DPPH· and FRAP assays followed by alginate with 1.0% (T4) and 0.5% (T3) BC extract, alginate with $CaCl_2$ (T2), alginate itself (T1), and control fruits. Overall, a decrease in antioxidant activity was observed on the 4th day, and the highest increase was detected on the 8th day in all treatments and thereafter gradual decrease with the increase in the period of storage. However, the decrease in antioxidant activity was substantially higher in the control than in all treated samples. All concentrations of BC extract significantly ($p < 0.05$) improved the antioxidant activity in coated guava fruits during the entire period of storage in FRAP assay. Research demonstrated that edible coatings modify the internal atmosphere of fruits (Hasan & Nicolai, 2014; Nair et al., 2018b). Consequently, the metabolic activities and the breakdown/oxidation of phenolics, flavonoids, carotenoids, and ascorbic acid were unchanged (Gonzalez-Aguilar et al., 2010) thus, resulting in an increase in the antioxidant activity in coated fruits during storage (Frusciante et al., 2007). Moreover, Etemadipoor et al. (2020) reported higher levels of phenolics, flavonoids, and ascorbic acid content correspond to the higher antioxidant activity in coated guava fruits. In this


A
B
C
D
E
F
μM β-carotene/g fresh weight
TPC mg GAE/g of fresh weight
TFC mg QE/g of fresh weight
μM Trolox Equ./g of fresh weight
μM Fe(II) Equ./g of fresh weight
α-glucosidase % Inhibition
Control
T1
T2
T3
T4
T5
Storage time (day)
Storage time (day)

◂**Fig. 5** Effect of alginate coating enriched with BC extract on the total carotenoids (**A**), TPC (**B**), TFC (**C**), antioxidant activity DPPH· (**D**) and FRAP (**E**), and α-glucosidase inhibitory activity (**F**) of guava fruits stored at 11 ± 1 °C and 85 ± 2% RH for 16 days. Note: T1 = 2% alginate + 5% glycerol + 1% tween, T2 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride, T3 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 0.5% BC extract, T4 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 1.0% BC extract, and T5 = 2% alginate + 5% glycerol + 1% tween + 4% calcium chloride + 2.0% BC extract; and different letters (a, b, c, d, e, and f) indicate significant differences at $p < 0.05$

study, alginate coating enriched with BC extract modified the internal atmosphere (Fig. 2) and suppressed the ripening process of guava fruits (Fig. 3C) and represented higher amount of ascorbic acid (Fig. 3D), TPC (Fig. 5B), and TFC (Fig. 5C) causing higher antioxidants activity. Similar results also were noticed in jamun fruits (Baraiya et al., 2015), guava fruits (Nair et al., 2018b), and mandarin fruits (Chen et al., 2016) when edible coating enriched plant extract.

α-Glucosidase Inhibitory Activity

The α-glucosidase inhibitory activity of control and coated guava fruits were analyzed to investigate their potentiality as antidiabetic effects, and the results were shown in Fig. 5F. The α-glucosidase inhibitory activity was decreased over time whatever the treatments applied. Control fruits showed a drastic ($p < 0.05$) decrease in α-glucosidase inhibitory activity than BC extract-coated fruits at 8, 12, and 16 days of storage. The lowest decrease value was found in the treatments of 2.0% (T5) BC extract-enriched alginate coating followed by alginate with 1.0% (T4) and 0.5% (T3) BC extract, alginate with $CaCl_2$ (T2), and alginate itself (T1). The BC extract worked in a dose-depended manner in inhibiting α-glucosidase activities. Islam et al. (2021) reported that phenolic compounds provide inhibitory activity toward α-glucosidase enzyme. This is a key enzyme that regulates the absorption of glucose in the small intestine to control type 2 diabetes (Kalra, 2014). In this research, the effect of BC extract-enriched alginate coatings on guava fruits was significantly effective on the inhibition of the activity of this enzyme. Consequently, the use of BC extract-enriched alginate coating in guava fruits could help for antidiabetic benefits in human diets due to its high content of total phenolics and flavonoids. Nevertheless, the α-glucosidase inhibitory activity of edible coating applied on guava fruits in this study was not possible to compete with previous research due to inadequate data.

Conclusion

Formulation of edible coatings with the inclusion of plant extracts/essential oils has recently gained interest to improve the overall quality of fruits with an extended shelf life as it enhanced the functionality of coatings. This study confirmed the improvement of the quality of guava fruits remarkably by the application of alginate coatings formulated with the inclusion of black cumin extracts. The inclusion of black cumin extract into alginate coating not only improved the physicochemical quality attributes (color, firmness, and weight loss) but also worked effectively to retain the nutritional quality parameters (phytochemicals such as vitamin C, total phenolics, and total flavonoids) by retarding the respiration rate and thereby delaying the ripening of guava fruits. Moreover, the combined application of the alginate coating and black cumin extract also maintained the biological functions such as antioxidant and antidiabetic activity of guava fruits. Therefore, the application of alginate coating enriched with black cumin extract could be considered as a suitable treatment in increasing shelf life and conserving the quality of guava fruits. However, more researches are needed to understand the efficiency of black cumin extract in edible coating development with various polysaccharides, proteins, and lipids and their effect on various fruits and vegetables with sensory evaluations. Moreover, the black cumin extract and its constituents may appear to have toxicity at high doses on humans. Therefore, further research should be also carried out on both animal and human tissues to verify the toxicity levels of black cumin extracts.

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Availability of Data and Materials Data will be available on request.

Declarations

Conflict of Interest The authors declare no competing interests.

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